ABSOLUTE NEUTRON FLUX FROM A Raα+Be SOURCE *

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ABSTRACT. The absolute flux of neutrons from a (Raα+Be) source has been determined by the method of "thermalisation" (Barschall, 1952). A large volume of $MnSO_4$ solution is activated by thermalised neutrons from the Raα+Be source held at the centre and the solution activity measured by a specially constructed immersion β-ray counter. The activity of Mn^{56} with reference to the neutron beam is calibrated with the help of an end window β-ray counter designed for the purpose. Detailed corrections for back-scattering, and self absorption of the β-rays, geometry and efficiency of the end-window counter, finite size of the source etc. have been applied. The absolute flux has been determined to be $F_0 = 13.2 \times 10^6$ neutrons per gram per second with a probable error of ±25 %. Values of F_0 determined by other workers for a similar source have been compiled for comparison. The approximate value supplied by the manufacturer of the neutron-source is 1.3×10^6 neutrons per sec. for a 100 mgm Ra+Be source of this type and it agrees well with the present determination.

INTRODUCTION

The neutron flux from a (Ra + Be) source has been defined as the number of neutrons of all velocities emitted in all directions from the source per second per gramme of its radium-content. The knowledge of the absolute neutron flux from a permanent neutron source is essential in determining the cross section of nuclear reactions produced by the neutrons from the source, Measurement of neutron flux is also necessary in determining the cross section of reactions in which charged particles interact with nuclei to produce neutrons. Various methods exist for the measurement of neutron flux from a source. An excellent review of these methods has recently been given by Barkchall, Rosen, Tasches and Williams(1952). If the neutron source is a mono-energetic one, the methods of 'recoil particle' and 'the associated particle method' are considered to be quite accurate. In the recoil particle method a thin foil of radiator made of a light material is chosen in which the elastic scattering of the fast neutrons is practically the only important interaction of the neutrons with the nuclei of the material. If the cross section of the elastic scattering process is known from separate transmission experiments, the flux of the neutrons can be determined by counting the number of recoil nuclei from the radiator in a fixed geometry. Any single absorption process, such as, (n,α)-reaction in $boron^{10}$, can also be used likewise. The associated particle method is quite simple in principle. Certain nuclear reactions which act as sources of deutrons emit a charged particle with each neutron produced in the reaction. If the charged particle is sufficiently energetic and also

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otherwise suitable to produce ionisation pulses, detection of these would give the number of neutrons emitted from the source. For example, the neutrons produced from the reaction D^2 (d, n) $He^3 + Q$ can be counted by counting the He^3 nuclei produced in the reaction. The method, however, is limited in its applicability, as in many neutron sources the angular distribution of the associated praticle is not known ; moreover in many cases suitable associated particles are not available, and the technique of measuring ionisation pulses due to associated particles which are not very light is as yet undeveloped. Both these methods are are also not very suitable when the neutrons from the soure have got a wide energy spectrum, since the charged particles in the above methods may not be detectable if they are of very low energy. The method of 'thermalisation' would be particularly suitable to determine neutron flux from a polyenergetic neutron source such as the (Ra-α + Be) neutron source. The neutron source in this method is placed in a moderating medium distributed symmetrically about the source. A radioactive indicator such as a metal foil (In 116 ; 57 minutes) or a substance like Mn^{56} (2.5 hours) as sulphate in solution can be used to detect the thermalised neutrons. The volume of the moderator must be so large that (1) neutrons of all velocities from the source are thermalised by elastic collision with its nuclei and brought within the energy range in which the detector is sensitive and (2) no neutron escapes out of the system. The activity of the detector has to be calibrated in terms of a standard neutron source strength. The principle of the method was first given by Amaldi and Fermi (1936) and has been used by many workers (Walker, 1945, Neal *et. al.* 1946, Alder and Huber, 1949) with minor variations in the method of calibration or the technique of measurement employed. In the present work the method of thermalisation has been employed with an aqueous solution of manganese sulphate using the 2.5 hour Mn^{56} as detector. The radioactivity produced in Mn powder by neutron capture is also absolutely determined by using a small carefully calibrated end-window counter, which instrument, we believe, would be a simple but powerful tool for such calibrations if its technique can be perfected.

For equilibrium activation of a radioactive indicator by a neutron source, the rate of neutron capture would be equal to the initial rate of decay of the active indicator nuclei and the rate of activation would thus be given by

$$A_1 = \int_{E_t}^{E_0} n_0 \sigma(E)\, F(E) dE,$$

where n_0 = the number of the target nuclei present, $F(E)$ = the flux of neutrons in the energy range E and $E + dE$, $\sigma(E)$ is the corresponding neutron capture cross section, and the detector is sensitive to the thermal neutrons between the threshold energy E_t and the upper limit E_0. If the activity produced in the solution is mechanically integrated by thoroughly mixing up the solution, the integrated activity $A_0 \approx$ const, F_0 would be a direct measure of the total neutron flux. If now the solution is surrounded by a uniform

layer of an absorber, and exposed as before to the indicator, some of the neutrons will be captured in the absorber and the rest will go to activate the indicator. Let this number transmitted through the absorber be F and the reduced initial integrated activity of the indicator $A \simeq$ const. F. Hence it follows :

$$\frac{F}{F_0} = \frac{A}{A_0} = R\,; \quad 1 - R = \frac{F_0 - F}{F_0} = \frac{a}{F_0},\ i.e.\ F_0 = \frac{a}{1-R}$$

where a denotes the absolute activity of the absorber in the second experiment. Thus the required neutron flux F_0 would be obtained by measuring the absolute β-activity of the absorber, a, and the ratio R of the initial activities of the solution exposed to the source with and without the absorber.

EXPERIMENT AND OBSERVATIONS

(*i*) The indicator substance Mn^{56} in the form of $MnSO_4$ was dissolved in water (moderator) to make a 10% solution. The solution was kept in a cylindrical drum, 30″ high, 20″ diameter, nearly full. These dimensions ensure, as some preliminary experiments showed, the slowing down of all the fast neutrons from a Ra α + Be source to thermal velocities within the volume of the solution. The neutron source, kept at the centre of the solution, irradiated the solution for 15 hours. After removal of the of the source, the solution was thoroughly stirred for mechanical integration

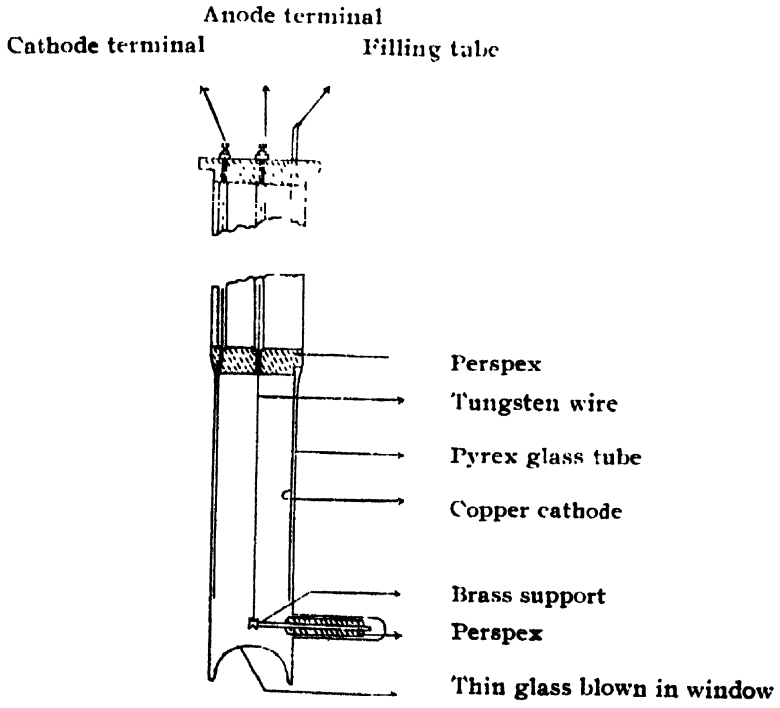
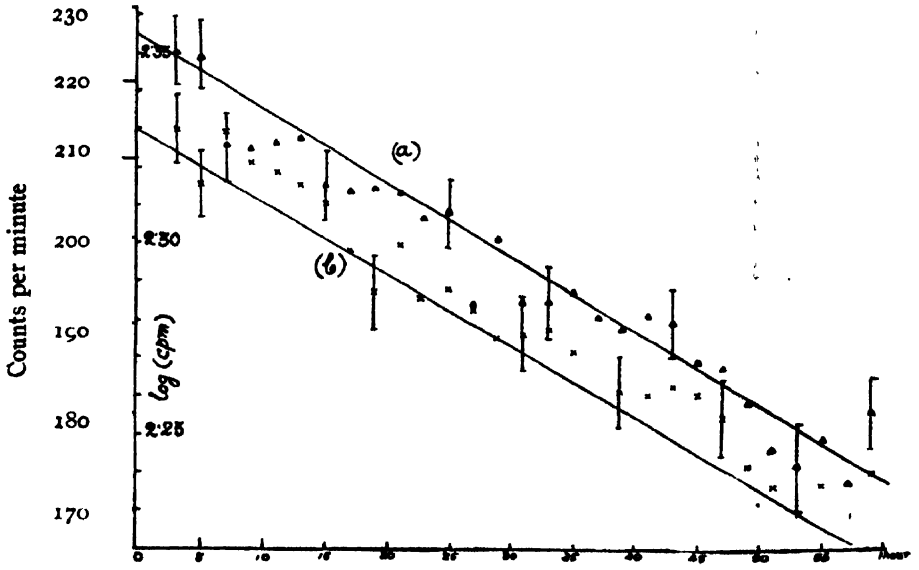


FIG. 1

Immersion counter : cathode length ~ 8.5 cm, total length ~ 57 cm, cathode inner diameter ~ 2.2 cm.

of its activity. The solution activity was measured by a specially designed immersion counter (figure 1). Sixteen reliable sets of observations were taken and in each case the activity was followed for a period of 4 hours. Average of all sets of readings (after subtracting the back-ground) is shown in figure 2(*a*) on a semi-logarithmic plot. An extrapolation of the straight



FIG, 2

Activity of manganess sulphate solution
(*a*) Without absorber (*b*) With Mn-absorber
Initial activity of (*a*) =227 count per min., (*b*) =214 count per min.

line to zero time gives the initial activity of ~227 counts per minute.

(*ii*) The neutron source is covered on all sides by a uniform layer of

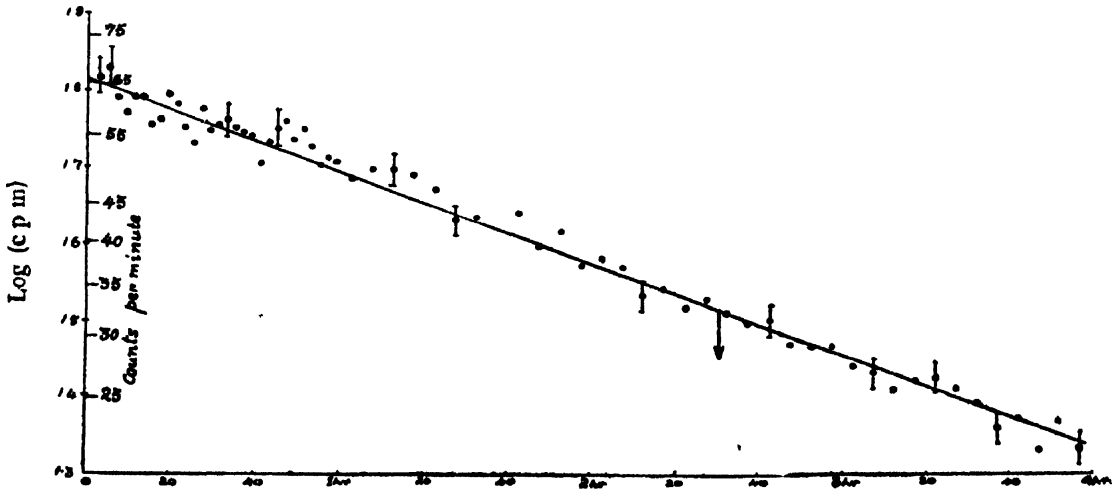


FIG. 3

Manganese powder activity

pure metallic manganese powder (absorber, total weight = 500 gm) and the solution exposed to this source for 15 hours. The initial activity of the solution, after removal of the source, is determined in an identical fashion as above. The initial activity obtained was ~214 cpm, as follows from figure 2(*b*). It will be seen from the plots that the statistical error of the observed initial activity is less than 2 %. But the reduction in activity in the second case (*b*) being small, though finite, the probable error of the ratio R becomes quite considerable. It was felt, however, that in order to obtain better statistics, an inconviniently large number of observations would be necessary, in course of which it would be difficult to maintain constancy of counting conditions. Within the limits of the present accuracy therefore we obtain $R = 214/227$, giving $(1-R) = 5.8$ % with a probable error of about 20 %.

(*iii*) For determining a the absolute activity of the absorber, the Mn powder in experiment (*ii*) was thoroughly mixed up after removing the source and the initial activity of a small sample (average weight ~ 0.0607 gm.) was found by means of a well calibrated end-window counter under well defined geometry. Knowing the mass of the sample and the total mass exposed, a is calculated (after correcting for geometry, back scattering, self-absorption of the β-rays etc.)

The effective aperture of the window of the counter was found out by measuring the rate of counting when a collimated β-ray source was scanned across the counter window, both along the two mutually perpendicular diameters of the window with the source held normal to the window, and the source held against the window-centre at various angles with the counter axis. Out of an aperture of 10.4 mm. of the window, about 7.0 mm. was found to be effective. Correction experiments for the determination of the of the amount of back scattering of β-rays from the source holder was performed similar to that given by Brutt (1949) and a correction factor of 0.9 was obtained. The method given by Aten (1950) was slightly modified for the measurement of self-absorption of the β-rays in the sample layer. A correction factor of 1/0.62 was estimated. The usual solid angle and planar source corrections were also applied. Absorptions due to the window and air gap between the Mn sample and the window were found negligible. With an initial activity of 65.3 cpm observed for the sample (figure 3), we obtain

$$a = \frac{65.3 \text{ counts}}{60 \text{ sec.}} \cdot \frac{500 \text{ gm.}}{0.0607 \text{ gm.}} \cdot \frac{0.9}{0.62} \cdot \frac{4\pi}{0.425 \times 2\pi} \cdot \frac{1}{0.85}$$

$$= 7.25 \times 10^4 \text{ disintegrations per second.}$$

This gives a total neutron flux

$$F_0^* = \frac{a}{1-R} = 1.25 \times 10^6 \text{ neutrons per sec.}$$

from the 95 mgm Ra + Be neutron source used, which is equivalent to $F_0 = 13.2 \times 10^6$ neutrons per gm per sec with a probable error of about ± 25 %.

CONCLUSION

The absolute neutron flux of a 100 mgm (Ra α + Be) source of this type has been roughly indicated by the manufacturer of the source to be ~1.3 million neutrons/sec. This compares very well with the value determined by us. Similar measurements made on the (Ra α + Be) neutron sources by other workers are also available. The values obtained by some of the authors are collected below for comparison.

Author	Absorber used	F_0 (neutrons per gm/sec)
Paneth, Gluckauf and Loleit (1936)	Boron	6.7×10^6
Ladenburg, Kanner (1937)	?	6.0 ,,
Walker (1945)	Boron	11 8 ,,
Seidel, Harris (1947)	Boron	11.0 ,,
O'Neal and Scharff-Goldhaber (1946)	Manganese	6.8 ,,
Alder and Huber (1949)	,,	6 3 ,,
Bracci, Facchini and Germagnoli (1950)	Indium	6.0 ,,

As is well known the (Ra α + Be) source cannot be regarded as a very permanent neutron source, since its neutron flux is likely to vary slightly from source to source depending on factors like coarseness and packing of the grains constituting the source and alterations in these with time. This may account for differences in the values observed by various authors. Modern improvements in the technique of preparation of natural neutron sources may be responsbible for the higher values of the flux we have obtained. It must be stressed, however, that the estimated accuracy of the present value is quite low (certainly not better than ±20 %), the main uncertainities being the fluctuations observed in the solution activity and the low reduction in the activity with absorber screening the neutron source. The method of thermalisation can therefore be applied only for calibrating good secondary neutron sources in a laboratory.

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